MULTIFOCAL OPHTHALMIC LENSES

Field of the Invention

The invention relates to ophthalmic lenses. In particular, the invention provides lenses that use more than one optical power, or focal length, and are useful in the correction of presbyopia.

Background of the Invention

As an individual ages, the eye loses its ability to accommodate, or bend the natural lens, to focus on objects that are relatively near to the observer. This condition is known as presbyopia. Similarly, for persons who have had their natural lens removed and an intraocular lens inserted as a replacement, the ability to accommodate is totally absent.

Among the methods used to correct for the eye's failure to accommodate is the use of lenses, both spectacle and contact lenses, that provide correction for both distance and near visions. Among the contact lens designs that have been proposed for presbyopia correction are lenses in which the design is independent of the pupil size meaning that the designs provide corrections for pupil variations due to lighting and object fixation distance. Examples of such designs are those that include optical zones of pie-sliced, checkerboard and hexagonal patterns on either or both surfaces of the lens. However, these designs are disadvantageous in that they do not easily allow equal optical performance across the pupil variations.

Additionally, both a spiral diffractive design and a spiral-printed design are disclosed in United States Patent No. 5,408,281. The diffractive design of this patent is disadvantageous in that it is difficult to manufacture using standard manufacturing techniques. The printed spiral design serves to achieve a wavelength

or color transmission difference in each of the spiral bands upon surface on which it is printed. Thus, lens manufacturing requires a wavelength selective coating or paint to be placed in a spiral pattern on the lens surface or the doping of different spiral bands with different dyes.

Therefore, a need exists for a design that overcomes some or all of the disadvantages of the known designs.

Brief Description of the Drawing

FIG. 1 is a plan view of first embodiment of an optic zone of a lens of the invention.

Detailed Description of the Invention and Preferred Embodiments

The invention provides methods for correcting the eye's lack of ability to accommodate, lenses for such correction, and methods for producing the lenses of the invention. The lenses of the invention utilize a refractive surface having a spiral pattern to distribute the distance and near vision power on the lens' surface. The design of the invention is advantageous in that, due to the area ratio value maintained for all circular areas centered in the center of the spiral pattern, it permits zones of near and distance vision correction having equal area ratios regardless of pupil size

In one embodiment, the invention provides an ophthalmic lens for a lens wearer, comprising, consisting essentially of, and consisting of a refractive surface comprising, consisting essentially of, and consisting of an optic zone having an area of distance optical power, wherein interspersed within the area of distance optical power and in a substantially spiral pattern is an area of near optical power.

By "ophthalmic lens" is meant a spectacle, contact, intraocular lens, or the like, or combinations thereof. Preferably, the lenses of the invention are contact lenses. By "distance optical power" is meant the amount of refractive power required to correct the wearer's distance vision acuity to the desired degree. By "near optical power" is meant the amount of refractive power required to correct the wearer's near vision acuity to the desired degree.

In the lenses of the invention, one or both of the front (object side) and back (eye side) of the lens has an area of distance power within the optic zone. Within this area of distance optical power is near optical power distributed in a substantially spiral pattern. Referring to Fig. 1, optic zone 10 is shown in which area 11 is seen, which area is of a radius of curvature effective to correct the lens wearer's distance vision acuity to the desired degree. Within area 11 is area 12, which area is of a radius of curvature effective to correct the wearer' near vision acuity to the desired degree.

One ordinarily skilled in the art will recognize that the near and distance zones making up the spiral pattern are of different refractive powers and the powers are being placed onto a surface of a lens having a constant center thickness. Thus, in all embodiments of the invention, sag differences between the near and distance vision zones are eliminated by adjusting instantaneous surface curvature, or slope, at the boundaries between the zones so that smooth transitions between the zones results. This may be accomplished by use of standard, commercially available computer aided design software along with ray tracing software or optical ray tracing software.

The spiral pattern of the invention may be on the front or back surface of the lens. Alternatively, a spiral pattern of plano and near power may be on one surface with the opposite surface being all distance power desired for the lens. Preferably,

the distance and near spiral pattern on one surface is used, and more preferably, that pattern is on the front surface.

Any suitable mathematical equation may be used to generate the spiral design. A preferred equation for generating a 50:50 ratio of distance optical power to near optical power is:

$$R = e^{a\theta} - 1$$

wherein R is the radius in mm, a is a constant, and θ is the circumference angular position in radians. If the constant a is chosen as 0.10246, then for an 8 mm diameter optic zone of $R_{max} = 4$, there may be traced a spiral line that goes around 2.5 times before reaching the edge of the optic zone. If a spiral line is created that uses points between the points for each θ and $\theta + 2\pi$ paired point on the first spiral line, two equal area spiral zones are created. By varying the fractional position between the θ and $\theta + 2\pi$ pairs, the zone area ratios can be varied.

The ratio of the lens' area devoted to the distance and near optical powers must be such that it is effective to provide the visual acuity correction desired for the lens wearer at all of the wearer's various pupil fixation sizes. These ratios of powers may be determined by any known method including, without limitation, optical software useful in gauging and optimizing the optical performance of a design. Suitable software includes, without limitation, Zemax available from Focus Software™.

In the lenses of the invention, the distance and near optical powers are spherical powers. Additionally, the distance and near optical power zones may be of any desired and practicable dimensions. The optic zone may be, and for soft contact lenses preferably is, surrounded by a non-optical lenticular zone. One ordinarily

skilled in the art will recognize that bevels, slab-offs, and the like may be used in the lens periphery.

Contact lenses useful in the invention may be either hard or soft lenses. Soft contact lenses, made of any material suitable for producing such lenses, preferably are used. The lenses of the invention may have any of a variety of corrective optical characteristics incorporated onto the surfaces in addition to distance and near optical powers including, without limitation, cylinder power, prism power, and the like, and combinations thereof. Additionally, one or more surfaces of the lens may be surfaces calculated from topographic measurements, or topographically–derived surfaces.

The lenses of the invention may be formed by any conventional method. For example, the spiral pattern formed therein may produced by diamond-turning using alternating radii. The pattern may be diamond-turned into the molds that are used to form the lens of the invention. Subsequently, a suitable liquid resin is placed between the molds followed by compression and curing of the resin to form the lenses of the invention. Alternatively, the pattern may be diamond-turned into lens buttons.